



13281 U.S. PTO  
030404

### Title of the Invention

Light-emitting Semiconductor Device Having Enhanced Brightness

### Cross-References to Related Applications

Not Applicable

### Statement Regarding Federally Sponsored Research or Development

Not Applicable

### Description

#### Field of Invention

[0001] This invention relates to a light-emitting semiconductor device having enhanced brightness, particularly to one for enhancing current distribution of a front contact in a light emitting diode, so as to enhance the light emitting efficiency of a light-emitting semiconductor.

#### Background

[0002] The principles lying behind luminance of light emitting diodes relate to passing current sequentially through P-N junctions of a semiconductor to generate light, wherein AlGaInP is implemented in high brightness red, orange, yellow and yellowish green LEDs, AlGaInN is in blue and green LEDs. The process of metal organic vapor phase epitaxy (MOVPE) is commonly adopted in the mass production of the LEDs, while the light-emitting components are of the structures, including: homo-junction (HOMO), single-heterostructure (SH), double-heterostructure (DH), single-quantum well (SQW) and multiple-quantum well (MQW) or other appropriate structures.

[0003] The structure of a conventional light emitting diode is illustrated in Fig. 1A, including, from the top down, a front contact 11, an active layer 12, a substrate 10 and a back contact 13. The active layer 12

is formed by a light-emitting material, such as AlGaInP or AlGaInN by adopting MOVPE. After current is injected through the front contact 11, the current will pass through the active layer 12 and the substrate 10 to flow towards the back contact 13. Light is emitted when the current flows through the active layer 12. However, the low carrier mobility and high resistance of the active layer made of AlGaInP or AlGaInN results in poor electric conductivity of the AlGaInP or AlGaInN. When current is applied to the front contact located above the active layer 12, even if a capping layer 14 (or window layer) is added to enhance the current distribution to make minor improvements to the current distribution, the current is still concentrated at the lower portion of the contact such that the primary emitting regions are mainly concentrated at and next to the lower portion of the contact, as illustrated in Fig. 1B.

[0004] The refractive index ( $n=3.4\sim3.5$ ) of most materials for making semiconductor LEDs is greater than the surrounding refractive index ( $n=1\sim1.5$ ,  $n=1.5$  for epoxy). In other words, a great portion of the light emitted by a semiconductor LED is completely reflected back to the semiconductor by the interface between the semiconductor and its exterior epoxy. The portion of the light that has been completely reflected is then absorbed by the active layer, the contacts and the substrate thereby reducing the actual luminance beneficial results of the LED (as shown in Fig. 1C).

[0005] To enhance the current distribution, improvements have been made to the structures and materials, such as that disclosed in US Patent No. 5,008,718 by Fletcher et al., where a capping layer 15 (or window layer), made of GaP, GaAsP and AlGaAs having a low resistance value and being pervious to light, is added between the front contact and active layer, as shown in Fig. 1D. The objective of using this capping layer is to enhance the current distribution flowing from the front contact. As described in the '718 patent, to improve the current distribution, the capping layer is preferred to be in the range from 150 to 200 micrometers thick to enhance the luminous intensity by 5 to 10 times. However, the increasing thickness of the capping layer also increases the time and cost required for MOVPE epitaxy thereby significantly increasing the cost of the epitaxy. In addition, the distribution ability is extremely relevant to the thickness. Hence, to ensure even current distribution, the thickness

must be at least 10 micrometers or the current crowding problem cannot be effectively resolved.

[0006] Another measure is to change the design of contacts. F. A. Kish and R. M. Fletcher suggested re-designing the contacts to include fingers 16 (as shown in Fig. 1E) or extended with Mesh lines 17 (as shown in Fig. 1F), to resolve the current crowding problem in LEDs. The result, however, is not satisfactory because the inherent width of the Mesh lines extending from the contacts usually ranges from 5 to 25 micrometers to ensure easy production. The number of fingers or Mesh lines of such a width must be limited in order to prevent excessive masking of light, such that the light emitted below the contacts would all be masked by the fingers or Mesh lines. Since the current located exactly below the contacts are most intensive to result in intensive illumination, the metal meshes mask the regions that are intensively illuminated. However, reducing the number the metal meshes will cause poor current distribution at some of the luminous regions E so as to affect the light-emitting effects (as shown in Figs. 1G to 1H).

[0007] To improve the current distribution, this invention discloses another design for the contacts so as to provide even current distribution and to reduce the regions masked by the contacts thereby enhancing the brightness.

### **Summary of Invention**

[0008] It is a primary objective of this invention to provide a light-emitting semiconductor device having enhanced brightness, where width of the meshes of the metallic patterns constructing the front contact ranges from 0.1 to 5 micrometers, thereby enhancing the light-emitting efficiency.

[0009] It is another objective of this invention to provide a light-emitting semiconductor device having enhanced brightness, where the metallic patterns constructing the front contact may be meshed, dotted, checkered or another other geometrical patterns that are evenly distributed above the entire active layer.

[0010] It is a further objective of this invention is to provide a light-

emitting semiconductor device having enhanced brightness, where the metallic patterns constructing the front contact does not mask the light illuminated by the active layer because the width of the metallic patterns is less than 5 micrometers.

[0011] To achieve the above objectives, this invention adopts the method comprising the steps of: forming an active layer on a substrate; forming a capping layer on the active layer to enhance current distribution, where a back contact is located on another side of the substrate and a front contact is located above the capping layer. This invention is characterized in that, the front contact is re-designed to reduce the width of metallic patterns constructing fingers or Mesh lines and to increase the number of the fingers or Mesh lines, so as to resolve the current crowding problem. When the metallic patterns are dimensioned to be 2 micrometers, even the light emitted by the active layer that is exactly located below the metal is still visible through the capping layer at a light-emitting angle of 3.8 to 18 degrees, whereby current concentration may be enhanced to improve the light-emitting efficiency.

#### **Brief Description of the Drawings**

[0012] These and other modifications and advantages will become even more apparent from the following detained description of preferred embodiments of the invention and from the drawings in which:

[0013] Fig. 1A is a cross-sectional view illustrating a conventional light emitting diode structure.

[0014] Fig. 1 B is a cross-sectional view illustrating the current distribution within a conventional light emitting diode structure.

[0015] Fig. 1C is a cross-sectional view illustrating illumination of light within a conventional light emitting diode structure.

[0016] Fig. 1D is a cross-sectional view illustrating a conventional light emitting diode with an addition of a capping layer structure.

[0017] Fig. 1E is a top view illustrating fingers extended from a front contact within a conventional light emitting diode structure.

[0018] Fig. 1F is a top plan view illustrating Mesh lines extended from a front contact within a conventional light emitting diode structure.

[0019] Fig. 1G is a cross-sectional view illustrating the current distribution within a conventional light emitting diode structure having fingers or Meshed lines extended from a front contact.

[0020] Fig. 1H is a cross-sectional view illustrating illumination of light within a conventional light emitting diode structure having fingers or Meshed lines extended from a front contact.

[0021] Fig. 2A is a cross-sectional view illustrating the current distribution within a first embodiment of a light emitting diode according to this invention.

[0022] Fig. 2B is a top plan illustrating a metallic mesh formed by a front contact within a light emitting diode structure.

[0023] Fig. 2C is a cross-sectional view illustrating the light-emitting structure located exactly below the contacts in prior art.

[0024] Fig. 2D is a cross-sectional view illustrating a second embodiment of a light emitting diodes according to this invention.

[0025] Fig. 2B is a top plan illustrating metallic dots formed by a front contact within a light emitting diode structure.

### **Detailed Description of the Invention (Preferred Embodiments)**

[0026] This invention may be implemented in enhancement of current distribution in light emitting diodes, by re-designing the front contact to enhance the light-emitting efficiency, wherein an active layer and a substrate may be modified based on the light wavelength of diodes. However, such modifications are not the features of this invention. In this invention, all examples use the term “active layer” to represent the primary structure of the LED component, including homo-junction, single-heterostructure, double-heterostructure, single-quantum well or multiple-quantum well.

#### **[0027] Example I:**

[0028] In Example I, a light emitting diodes (LED) is used to describe

the features of this invention. Fig. 2A is a cross-sectional view of a light emitting diode. First, an active layer 120 is formed above a substrate 100. The active layer may be of a double-heterostructure or a quantum well structure to enhance the light-emitting efficiency of the diode. Then, a capping layer 140 made of GaP, AlGaAs or ITO is then added above the active layer to increase the current distribution. A back contact 130 is located on another side of the substrate 100, and a front contact 210 is located above the capping layer 140.

[0029] In detail, the material of the substrate 100 is dependent on the material of the active layer 120. When the active layer 120 is made of AlGaInP, GaAs is selected to form the substrate. When the active layer 120 is made of AlGaInN. Any of sapphire, SiC, MgAlO<sub>4</sub>, ZnO, LiG<sub>2</sub>O<sub>2</sub> and LiAlO<sub>2</sub> may be selected to form the substrate. The active layer is preferred to be in the range from 0.3 to 3 micrometers thick. The capping layer 140 is preferred to be in the range from 10 to 50 micrometers thick. Both the active layer 120 and the capping layer 140 are formed by adopting MOVPE or Molecular Beam Epitaxy (MBE).

[0030] This invention discloses an effective measure for resolving the current crowding problem, where the front contact is re-designed to reduce the width of metallic patterns constructing fingers or Mesh lines and to increase the number of the fingers or Mesh lines, so as to resolve the current crowding problem and to enhance the light-emitting efficiency of the light-emitting diode. Example I suggests a metallic pattern. However, the exemplified pattern does not intend to limit the scope of this invention.

[0031] Fig. 2B illustrates a top plan of the diode. The contact 110 implemented in Example I still retains a metallic bonding pad for contacting the exterior. However, next to the contact 110 is completely arranged with metallic meshes 210 above the active layer 120. The metallic meshes 210 interconnect with the contact 110, to jointly serve as the front contact of Example I.

[0032] In a conventional light emitting diodes front contact having Mesh lines, the width of the Mesh lines are mostly in the range of 5 to 25 micrometers, such that the current can only be distributed to about 40 micrometers away from the Mesh lines, to leave a light-emitting vacant

of greater than 80 micrometers between the Mesh lines. Since the current below the contacts is most intensive, as shown in Fig. 2C, if the capping layer 15 has a width of 15 micrometers, given that the Mesh line 11 of the front contact each has a width of 15 micrometers and is spaced from each other by 60 micrometers, when the current is distributed to a point A in the active layer 12 that is located exactly below the Mesh line 11 of the front contact to cause illumination of the point A, the light-emitting angle must be greater than halved width of the front contact, or the light emitted by the active layer 12 will be masked by the Mesh line 11. The light-emitting angle  $\theta$  may be calculated as follows:

[0033] Thickness of capping layer 15 micrometers:  
 $d\cos 2\theta = 15$

[0034] Halved width of Mesh line 11 of contact:  
 $dsin 2\theta = 7.5$

(where d is the shortest distance at where point A will not be masked by the contact)

[0035]  $\tan 2\theta = 1/2 \rightarrow 2\theta \approx 53^\circ \rightarrow \theta \approx 26.5^\circ$

[0036] Generally speaking, the critical angle  $\theta_c$  of the material commonly used for light emitting diodes is approximately 18 degrees. In other words, when the refractive angle of the light is greater than 18 degrees, the light will be completely reflected back to the semiconductor by the interface between the semiconductor and its exterior, thereby reducing the actual LED luminous beneficial results of the LED. When the light generated in the light-emitting layer is dispersed by radiation, complete reflection will be observed outside the range of  $\theta_c$ . On the other hand, light will penetrate through the capping layer within the range of  $\theta_c$ . When the width of the mesh is greater than 10 micrometers, light emitted exactly below the contact, where there is the highest concentration, cannot penetrate through the mesh thereby affecting the light-emitting efficiency significantly.

[0037] By re-designing the Mesh lines each having a wider width to be constructed of equal-distant metallic meshes 210, as shown in Fig. 2B, can result in even concentration of the current distribution, thereby enhancing the light-emitting efficiency. The metallic meshes 210

suggested in Example I are dimensioned to 0.5 to 5 micrometers and evenly distributed above the substrate. Base on the above calculations, if the meshes are dimensioned to 2 micrometers with a capping layer having a thickness of 15 micrometers, the light-emitting angle  $\theta$  is calculated by,  $\tan 2\theta = 2/15 \rightarrow 2\theta \approx 7.6^\circ \rightarrow \theta \approx 3.8^\circ$ .

[0038] The reduction of the light-emitting angle  $\theta_c$  significantly reduces the region where the light emitted by the active layer is masked by the front contact. The light emitted by the enhanced current concentration, that is located exactly located below the contact, may now penetrate through the capping layer within the range of  $\theta=3.8$  to 18 degrees, so as to greatly increase the current concentration and the enhance the light-emitting efficiency.

**[0039] Example II:**

[0040] Example II discloses a further light emitting diodes (LED) to describe the features of this invention. Fig. 2D is a cross-sectional view of a light emitting diode, having a back contact, a substrate, an active layer and a capping layer that have the same structures as those in Example I. According to this invention, the substrate may a semiconductor substrate or any other appropriate substrates dependent on the applications of the LED.

[0041] Example II is characterized by a front contact that is divided into two layers, as shown in Fig. 2E. The metallic bonding pad -- a first layer 110 of the front contact, is the same as that adopted in the conventional light emitting diodes. The contact is located at a center of the diode to serve as the media for communicating and contacting the exterior. A second layer 220 of the front contact is located below the first layer 110 and embedded in an ITO layer 230. The second layer 220 of the front contact includes a metallic pattern having a reduced width and being in the form of numerous dots, so as to resolve the current crowing problem and to enhance the light-emitting efficiency of the light emitting diode. The dots are each dimensioned to 0.1 to 5 micrometers and evenly distributed above the active layer. Such a design significantly reduces the region where the light emitted by the active layer is masked by the front contact, and enables even current distribution to enhance the light-emitting efficiency. The metallic dots in Example II may be the

metallic meshes suggested in Example I or any other metallic patterns.

[0042] Two examples are disclosed in this invention to explain the changes made to the front contact for enhancing the current distribution. The front contact in Example I includes a metallic bonding pad and metallic patterns with reduced dimensions. The front contact in Example II includes two conductive layers; the metallic patterns that allow more variations in Example II are embedded in a transparent conductive layer and may be disconnected. The spirits of this invention, however, reside in the arrangement of the front contact above the active layer, with the metallic patterns constructing the front contact being dimensioned to 0.1 to 5 micrometers. So long as the metallic patterns are dimensioned to be sufficiently small so as to prevent the active layer from masking most of the light emitted, the metallic patterns may be configured to any geometrical designs.

[0043] This invention is related to a novel creation that makes a breakthrough in the art. Aforementioned explanations, however, are directed to the description of preferred embodiments according to this invention. Since this invention is not limited to the specific details described in connection with the preferred embodiments, changes and implementations to certain features of the preferred embodiments without altering the overall basic function of the invention are contemplated within the scope of the appended claims.